

EFFECTS OF BULK COMPOSITION ON PRODUCTION RATES OF COSMOGENIC NUCLIDES IN METEORITES\*; Jozef Masarik and Robert C. Reedy, Space Science and Technology Division, Mail Stop D436, Los Alamos National Laboratory, Los Alamos, NM 87545.

The bulk chemical composition of meteorites has been suggested as a main factor influencing the production of cosmogenic nuclides. Numerical simulations with Los Alamos Monte Carlo production and transport codes were done for  $^{21}\text{Ne}/^{22}\text{Ne}$  ratios and  $^{38}\text{Ar}$  production rates in meteorites with a wide range of compositions. The calculations show that an enhanced flux of low-energy secondary particles in metal-rich phases is the essential key for the explanation of experimentally observed differences in nuclide production processes in various meteorite classes.

Nuclides produced by the interaction of cosmic-ray particles with meteorites provide valuable information about both the meteorite and the cosmic rays. The accurate modeling of the production processes is necessary for the interpretation of measured concentrations. The bulk composition is one of the factors that influences final production rates by its effects on the shape of differential fluxes of primary and secondary nucleons and their total fluxes. These particle fluxes strongly depend on the multiplicities for production of secondary particles, which are functions of mass number. The transport phenomena are also dependent on the bulk composition. In stony meteorites, the average atomic and mass numbers vary by less than 15%. A substantial difference in inter- and intranuclear cascade development is expected for iron meteorites. The ranges of production rates for neon and argon isotopes in stones, stony-irons, and irons discussed in [1] were attributed to an enhanced flux of low-energy secondary particles, especially neutrons, in metal-rich phases. The bulk-composition problem was also discussed in [2,3]. However, the influence of a meteorite's matrix on the production of nuclides, especially by neutrons, needed more calculations. Our previous results [4] showed the influence of bulk composition on both secondary-particle production and particle transport, with there being higher fluxes of neutrons in irons than in stones.

In this paper, we present the results of the simulations of production rates of cosmogenic nuclides in meteorites with various bulk compositions. Our calculations are based on the Los Alamos LAHET Code System [5], which is a system of coupled Monte Carlo computer codes that treats the relevant physical processes of particle production and transport. A homogenous and isotropic GCR irradiation, corresponding to an averaged GCR primary cosmic-ray spectrum, of spheres with chemical compositions equivalent to average compositions for chondrites, mesosiderites, eucrites, and pallasites was calculated. Particle fluxes for the individual meteorites within a classes are very similar to that for a class average [4]. To avoid effects due to size, the spheres had the same radii of  $R = 106.5 \text{ g/cm}^2$  (corresponding to  $R = 30 \text{ cm}$  for L-chondrites). Production rate  $P$  of cosmogenic nuclide  $j$  at depth  $d$  in an irradiated meteorite with a radius  $R$  was calculated with

$$P_j(R, d) = \sum_i N_i \sum_k \int_0^\infty \sigma_{jik}(E_k) J_k(E_k, R, d) dE_k$$

where  $N_i$  is the number of atoms for target element  $i$  per kg of sample,  $\sigma_{jik}$  is the cross section for the production of nuclide  $j$  from target element  $i$  by particle  $k$ , and  $J_k$  is flux of primary and secondary particles of type  $k$  with energy  $E_k$ . For particles, only protons and neutrons are important. Production rates were calculated for concentric shells with thickness  $8.875 \text{ g/cm}^2$ . Statistical errors for the calculated particle fluxes were less than 5%. The reported composition of each individual meteorite was used in getting production rates. In some cases, these rates were averaged over the whole volume of meteorite for comparison with experimental measurements.

Our simulations confirm the importance of bulk composition on nucleon fluxes inside the meteorite and consequently on production rates of cosmogenic nuclides. Fig. 1 shows experimental [1] and our calculated ratios of the production rates for  $^{38}\text{Ar}$  from Ca to that from FeNi. These ratios strongly depend on the FeNi content of the matrix in which the production takes place. The ratio for L-chondrites with 23 % FeNi is about a factor of two lower than for mesosiderites with ~60 % FeNi. This difference can be explained by the influence of bulk composition on production and transport of nucleons that induce nuclear reactions producing  $^{38}\text{Ar}$ . The higher yield for the production of secondary, mainly low-energy, particles from heavy elements like Fe and Ni than from light elements like O, Mg, and Si is the main source of the calculated differences. These production differences are further increased with the transport of the produced particles, especially at lower energies. Both production and transport processes cause a higher flux of low-energy secondary particles in materials composed mainly of elements with higher atomic number, like Fe and Ni [4], accounting for the observed differences in the ratio of  $^{38}\text{Ar}$  from Ca to that from Fe.

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A similar effect is observed for the cosmogenic  $^{21}\text{Ne}/^{22}\text{Ne}$  ratio plotted on Fig. 2 as a function of the sample's  $\text{Mg}/(\text{Mg}+\text{Al}+\text{Si})$  ratio, the same format used by [1]. In all meteorite classes, the  $^{21}\text{Ne}/^{22}\text{Ne}$  ratio increases with decreasing  $\text{Mg}/(\text{Mg}+\text{Al}+\text{Si})$ . The  $^{21}\text{Ne}/^{22}\text{Ne}$  ratio for stony-irons is significantly lower than the lower limit found for L-chondrites and eucrites. The  $^{21}\text{Ne}/^{22}\text{Ne}$  ratio is thus sensitive to the bulk composition of the matrix in which the irradiation took place.

From these two sets of trends, we conclude that bulk composition can strongly affect the production rates of nuclides in meteorites. The production of cosmogenic nuclides can also be influenced by size, shape, and probably other effects that can complicate the unfolding of bulk-composition effects in real samples. However, in the two cases presented in [1] and here, the influence of bulk composition on particle fluxes, especially neutrons, is the dominant effect. Absolute production rates vary with the reactions involved. For example, in meteorites of the same mass,  $^{53}\text{Mn}$  is  $\sim 20\%$  higher in iron meteorites than in CI-chondrites.

**References:** [1] Begemann F. and Schultz L. (1988) *LPS XIX*, p. 51. [2] Englert P.A.J., Reedy R.C., and Michel R. (1990) *LPI Tech. Rpt. 90-05*, p. 11. [3] Michel R., Dragovitsch P. and Filges D. (1990) *Meteoritics*, **25**, 386. [4] Masarik J. and Reedy R.C. (1992) *Meteoritics*, **27**, 256. [5] Prael R.E. and Lichtenstein H. (1989) *Los Alamos Report LA-UR-89-3014*. \* Work supported by NASA and done under the auspices of the US DOE.

Fig. 1. Measured (with errors) [1] and calculated ratios for the production of cosmogenic  $^{38}\text{Ar}$  from Ca to that from metal samples are plotted as a function of the Fe and Ni content of the bulk meteorite. There are some variations due to the composition of each meteorite, but the trend is for this ratio to increase with increasing metal content.

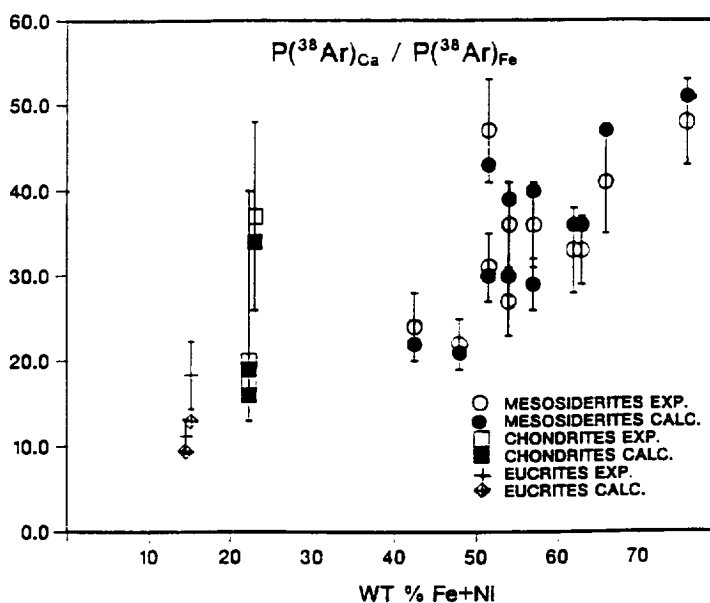


Fig. 2. Measured [1] and calculated  $^{22}\text{Ne}/^{21}\text{Ne}$  ratios are plotted as a function of the fraction Mg for the major elements making cosmogenic neon. The stony-iron meteorites have ratios lower than those for stony meteorites because of more low-energy neutrons in their metal.

